

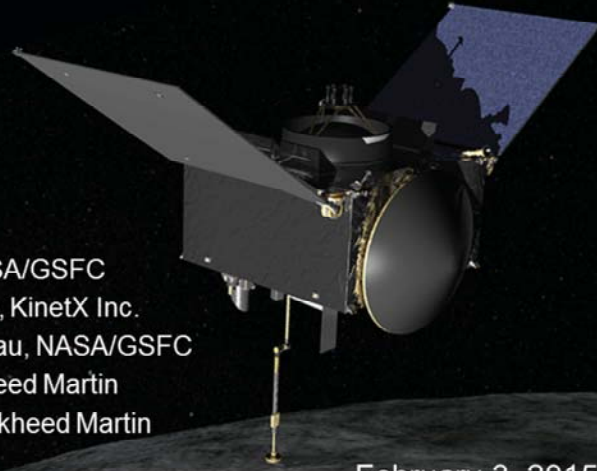


OSIRIS-REx™
ASTEROID SAMPLE RETURN MISSION

2015 GN&C Conference

OSIRIS-REx Touch-And-Go (TAG) Navigation Performance

Kevin Berry, NASA/GSFC
Peter Antreasian, KinetX Inc.
Michael C. Moreau, NASA/GSFC
Alex May, Lockheed Martin
Brian Sutter, Lockheed Martin



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Outline

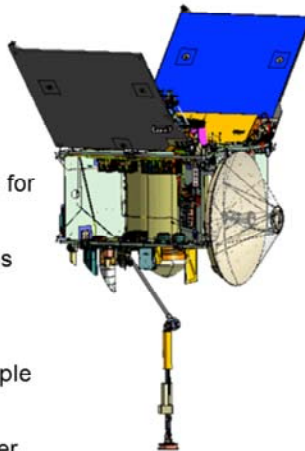
- OSIRIS-REx Mission Overview
- TAG Driving Requirements
- TAG Sequence Overview
- Navigation Errors
- Maneuver Execution Errors
- Other Errors
- TAG Results
- Final Remarks



OSIRIS-REx Mission Overview

Origins Spectral Interpretation Resource Identification Security Regolith Explorer (OSIRIS-REx) is the third mission selected as part of NASA's New Frontiers Program.

- Launch in 2016 and encounter asteroid (101955) Bennu in late 2018
- Develop detailed models of Bennu in an extensive proximity operations campaign over 5 months
- Conduct reconnaissance of candidate sample sites for 3 months and select the best one
- Conduct Incremental TAG rehearsals over 2 months
- Perform the TAG event to obtain at least 60 g of pristine carbonaceous asteroid regolith
- Return to Earth in 2023 in a Stardust-heritage Sample Return Capsule (SRC)
- Deliver samples to the NASA Johnson Space Center (JSC) curation facility for world-wide distribution

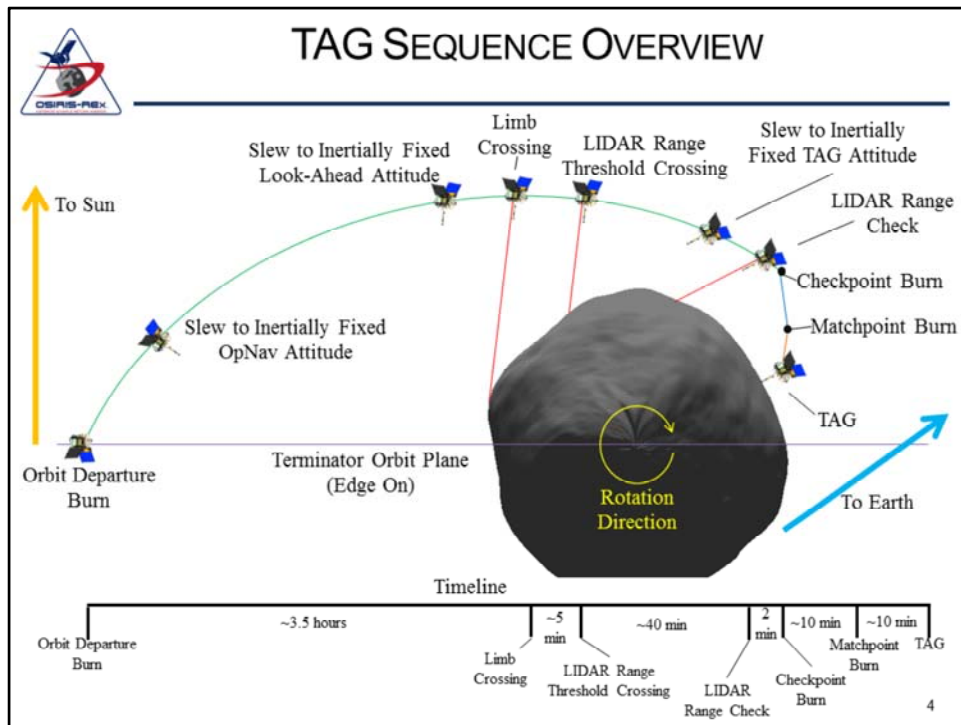




TAG Driving Requirements

- TAG Position Error ≤ 25 meters
 - Confidence Interval (CI) of 98.3% ($\sim 2.85\sigma$ for a 2-D Gaussian distribution)
 - Allocation of overall probability of success
- Horizontal Velocity Error ≤ 2 cm/s (3σ)
 - Minimizes the risk of tipping over during TAG
- Vertical Velocity 10 ± 2 cm/s (3σ)
 - Vertical velocity ≥ 8 cm/s to provide sufficient TAG contact time
 - Vertical velocity ≤ 12 cm/s to minimize the risk of tipping over during TAG

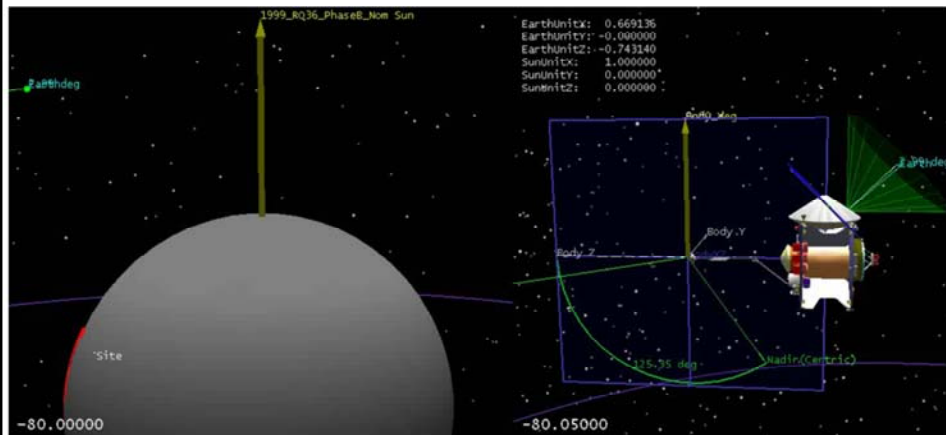
Prepared to answer questions about confidence interval...



there is a slew to Comm attitude after ODM



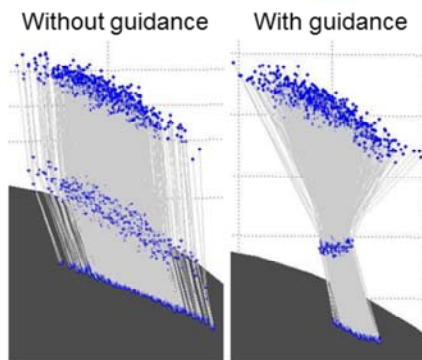
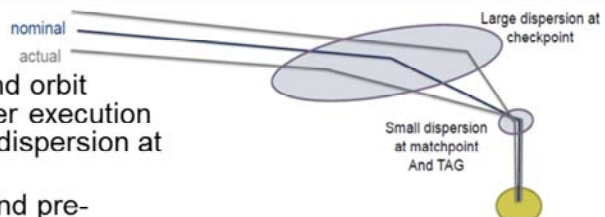
TAG VIDEO





ONBOARD GUIDANCE OVERVIEW

- Navigation error and orbit departure maneuver execution error lead to large dispersion at Checkpoint
- Range threshold and pre-Checkpoint LIDAR measurements allow closed loop corrections to Checkpoint maneuver to achieve original Matchpoint location
- Matchpoint corrected to original TAG approach trajectory
- Algorithm details provided in 2013 GN&C Conference paper entitled "OSIRIS-REx Touch-And-Go (TAG) Mission Design and Analysis"





Navigation Errors

	Position Uncertainty (3σ)			Velocity Uncertainty (3σ)		
	Radial (m)	In-Track (m)	Cross-Track (m)	Radial (mm/s)	In-Track (mm/s)	Cross-Track (mm/s)
Low GM	18.108	83.826	5.264	4.816	0.592	0.108
Nominal GM	12.483	52.619	3.795	3.922	0.506	0.031
High GM	11.599	41.612	2.687	3.652	0.572	0.059

- Measurements:
 - Radiometric Range and Doppler from Deep Space Network (DSN)
 - Optical navigation based on asteroid surface landmark tracking
- Error Sources:
 - Process noise
 - Measurement noise
 - Ground station location knowledge errors
 - Maneuver execution errors from previous burns
 - Asteroid ephemeris errors
 - Asteroid spin state errors (pole orientation and rate)
 - Force model errors (gravity, SRP, albedo, Infrared radiation, thermal imbalance)
- Uncertainty given at the Orbit Departure Maneuver (ODM)
- Data Cut-Off (DCO) is 24 hours before ODM

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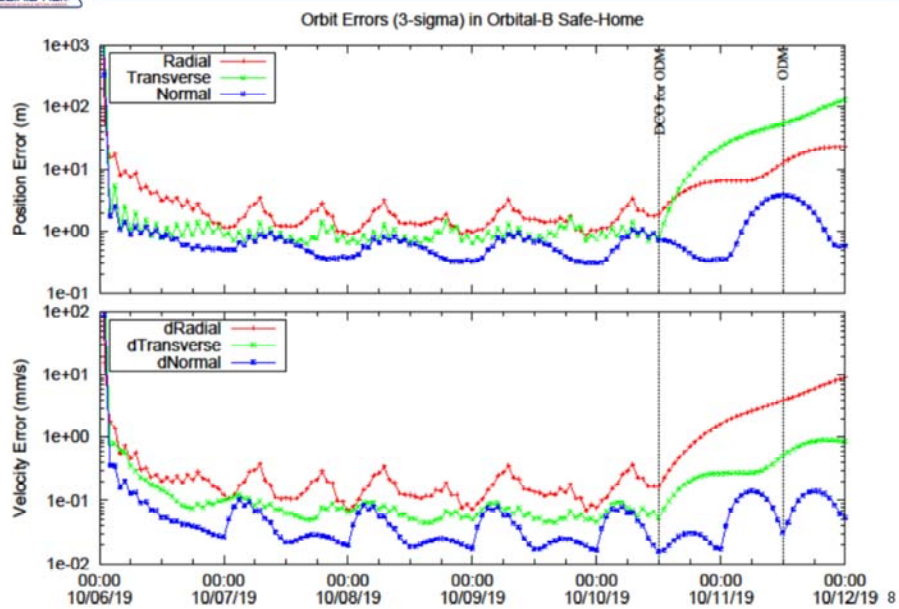
Introduce this section – *two dominant error sources – navigation prediction errors and maneuver execution errors*

This next set of charts summarizes the navigation errors assumed in the simulation, result of covariance analysis performed by my colleague Pete Antreasian...

Currently a large uncertainty in Bennu GM...



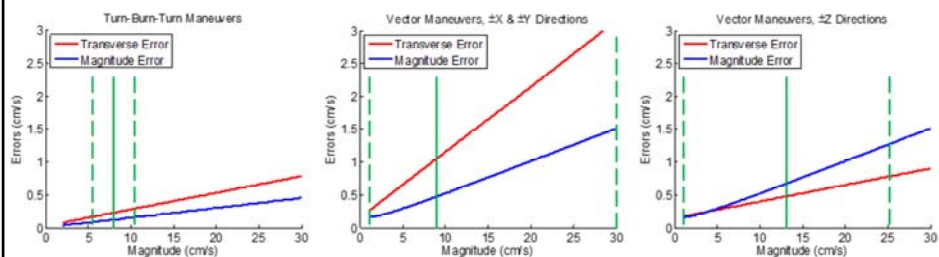
Navigation Errors Over Time (Nominal GM)





Maneuver Execution Errors

Body Direction	Magnitude Error (3 σ)	Transverse Error (3 σ)
ACS Turn-Burn-Turn (Orbit Departure) Maneuver Execution Errors:		
Z	$\sqrt{(0.3 \text{ mm/s})^2 + (0.015 \cdot \ \Delta \vec{v}\)^2}$	$0.3 \text{ mm/s} + 0.025 \cdot \ \Delta \vec{v}\ $
ACS Vector Burn (Checkpoint and Matchpoint) Maneuver Execution Errors in the spacecraft body directions:		
$\pm X$ & $\pm Y$	$\sqrt{(1.5 \text{ mm/s})^2 + (0.050 \cdot \ \Delta \vec{v}\)^2}$	$1.5 \text{ mm/s} + 0.100 \cdot \ \Delta \vec{v}\ $
$\pm Z$	$\sqrt{(1.5 \text{ mm/s})^2 + (0.050 \cdot \ \Delta \vec{v}\)^2}$	$1.5 \text{ mm/s} + 0.025 \cdot \ \Delta \vec{v}\ $



Green lines are min, mean, and max burn magnitudes



Other Error Sources for Monte Carlo

Parameter	Current Model
Low GM	3.4 m ³ /s ²
Nominal GM	5.2 m ³ /s ²
High GM	7.0 m ³ /s ²
Shape Model	2012 Nolan
Spacecraft wet mass	1182 kg

Parameter	Uncertainty (3 σ)
GM	0.15%
Spherical Harmonics	30%
SRP	10%
Bennu spin rate	0.1 sec/rev
Bennu spin axis	0.2 deg
Surface variation errors	3.3 m for Bennu 7.8 m for Itokawa
LIDAR measurement errors	noise: 10 cm + 1% of range bias: 10 cm + 1% of range
LIDAR pointing errors	13.2 mrad per axis

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shape model 10 m 1 sigma uncertainty at equator, 50 m at pole (per traj stds), resolution of 25 meters

Current Simulation: surface variation modeled as a variation on the simulated lidar ranges – two levels of variation considered.

In Flight: actual surface variations will be captured in 75 cm resolution shape model delivered during operations...



Checkpoint Dispersions

Control Errors (3-sigma)

	Position Dispersion (meters) Radial	Position Dispersion (meters) In-track	Position Dispersion (meters) Cross-track	Velocity Dispersion (cm/s) Radial	Velocity Dispersion (cm/s) In-track	Velocity Dispersion (cm/s) Cross-track
0 deg Latitude, Low GM	28.823	132.700	10.450	2.441	0.850	1.717
0 deg Latitude, Nominal GM	31.346	125.368	9.264	3.142	0.850	1.015
0 deg Latitude, High GM	40.194	135.795	9.484	4.098	0.903	0.867
-45 deg Latitude, Low GM	31.086	119.198	9.744	2.258	0.795	1.715
-45 deg Latitude, Nominal GM	27.034	117.511	9.520	2.966	0.833	1.059
-45 deg Latitude, High GM	32.918	132.562	9.297	4.009	0.935	0.868
75 deg Latitude, Low GM	53.385	58.066	8.273	1.212	1.152	0.990
75 deg Latitude, Nominal GM	34.104	57.749	7.358	1.405	0.813	0.623
75 deg Latitude, High GM	24.393	66.001	6.495	1.851	0.659	0.474



Checkpoint Prediction Errors

Onboard Checkpoint Position Knowledge Errors (meters, 3-sigma)

	Expected Bennu Surface	Expected Bennu Surface	Expected Bennu Surface	Itokawa Based Surface	Itokawa Based Surface	Itokawa Based Surface
	Radial	In-track	Cross-track	Radial	In-track	Cross-track
0 deg Latitude, Low GM	5.561	10.548	8.731	8.577	11.636	8.741
0 deg Latitude, Nominal GM	5.429	9.685	8.188	8.358	11.728	8.185
0 deg Latitude, High GM	6.228	9.285	7.764	9.029	11.447	7.761
-45 deg Latitude, Low GM	6.047	7.790	7.749	9.252	11.462	7.764
-45 deg Latitude, Nominal GM	4.906	4.835	7.814	8.105	6.921	7.808
-45 deg Latitude, High GM	5.368	5.292	7.381	8.525	7.548	7.379
75 deg Latitude, Low GM	9.155	15.496	5.316	13.506	21.249	5.399
75 deg Latitude, Nominal GM	6.223	7.419	4.991	10.339	12.406	5.145
75 deg Latitude, High GM	5.757	5.267	4.406	9.112	8.059	4.557

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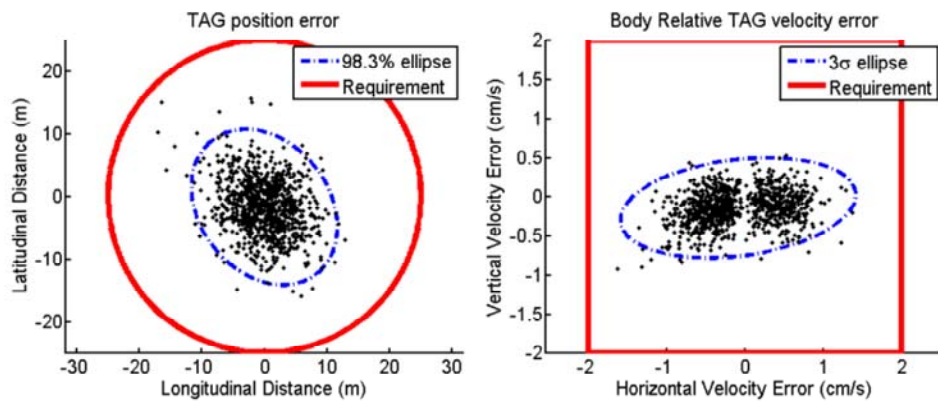


TAG Results Table

	TAG Position Error 98.3% Ellipse (meters)		Horizontal Velocity Error 3-sigma (cm/sec)		Vertical Velocity Error 3-sigma (cm/sec)	
	Expected Bennu Surface	Itokawa Based Surface	Expected Bennu Surface	Itokawa Based Surface	Expected Bennu Surface	Itokawa Based Surface
Requirement	25	25	2	2	2	2
0 deg Latitude, Low GM	15.609	15.792	1.622	1.624	1.300	1.310
0 deg Latitude, Nominal GM	15.031	15.299	1.462	1.474	1.152	1.167
0 deg Latitude, High GM	14.506	15.202	1.592	1.610	1.167	1.191
-45 deg Latitude, Low GM	15.179	15.368	1.644	1.724	1.011	1.025
-45 deg Latitude, Nominal GM	16.169	16.436	1.643	1.663	0.941	0.971
-45 deg Latitude, High GM	18.328	18.844	1.784	1.799	1.081	1.152
75 deg Latitude, Low GM	17.182	21.706	1.771	1.983	0.979	1.055
75 deg Latitude, Nominal GM	16.625	17.904	1.728	1.858	0.835	0.949
75 deg Latitude, High GM	20.417	20.721	1.910	1.971	1.009	1.149



Representative TAG Dispersions





Final Remarks

- This analysis has demonstrated TAG can be successfully conducted using a single baseline TAG design, meeting performance requirements for position and velocity for nearly all locations on Bennu.
- Maneuver execution error and navigation uncertainties are roughly equal as dominant error sources.
- Better initial navigation states resulted in improvements in the TAG accuracy by up to 26% and a reduction in the TAG velocity error by up to 25%